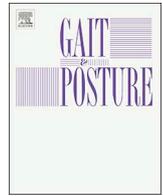




ELSEVIER

Contents lists available at ScienceDirect

Gait &amp; Posture

journal homepage: [www.elsevier.com/locate/gaitpost](http://www.elsevier.com/locate/gaitpost)

## Quantitative coronal plane motion of hindfoot during clinical flexibility assessments

Mark L. McMulkin\*, Shelley Mader, Tayler Elizondo, Glen O. Baird

Walter E. and Agnes M. Griffin Motion Analysis Center, Shriners Hospitals for Children® - Spokane, 911 W. 5th, Spokane, WA 99204, USA

### ARTICLE INFO

#### Keywords:

Coleman block test  
Tiptoe test  
Cavovarus  
Planovalgus  
Segmented foot model

### ABSTRACT

**Background:** Common pediatric pathologic foot presentations include cavovarus and planovalgus feet. Flexibility of the hindfoot is established for these two clinical presentations through the Coleman block (eversion) and tiptoe tests (inversion).

**Research question:** The purposes of this study are to establish typical quantitative eversion and inversion motion of the hindfoot during Coleman block and tiptoe tests using 3-D motion capture and demonstrate feasibility of using this data to assist in making treatment decisions.

**Methods:** Segmented foot model kinematics were collected for this prospective descriptive study with a focus on coronal plane inversion and eversion of the hindfoot relative to the tibia. Typical standing hindfoot position, with the feet plantigrade, was determined prior to performing the tiptoe test. Maximum hindfoot inversion was extracted from the tiptoe test. Maximum hindfoot eversion was extracted from the Coleman block tests.

**Results:** 32 typically developing subjects (age range 5–21 years) completed this study. Hindfoot motion data showed a mean standing foot position of 1° eversion, 10 degrees inversion during tiptoe test and 6 degrees eversion during the Coleman block test.

**Significance:** Establishing control values for hindfoot flexibility can assist with making clinical treatment decisions for disorders of the foot. At our center, clients who present to the Motion Analysis Center with foot concerns receive segmented foot model quantitative assessment of hindfoot flexibility with Coleman block and tiptoe tests as appropriate.

### 1. Introduction

In the pediatric population, common foot presentations include cavovarus and planovalgus feet. Establishing flexibility of the hindfoot for these two clinical presentations is critical in assessment and treatment planning. In the cavovarus foot, a Coleman block test [1] assesses flexibility of the hindfoot to correct from an inverted position as compensation for a plantarflexed first ray. For children with planovalgus feet, a tiptoe test [2,3] assesses flexibility of the hindfoot to correct from an everted to inverted position by activating the plantarflexor muscles.

Typical multi-segment walking kinematic analysis is often not adequate to elicit or differentiate foot disorders. For example, during typical walking an adolescent with planovalgus might walk with eversion of the hindfoot relative to the tibia throughout stance and swing. However, it must be established if the hindfoot is flexible and corrects to neutral/inversion. Conversely, a child with a cavovarus foot might walk with hindfoot inversion in stance. A Coleman block test can assist in determining if this is related to a plantarflexed first ray. Hindfoot

flexibility during tiptoe and Coleman block tests has not been quantified for typically developing children as a baseline to better understand flexibility of pathologic feet, in treatment decision making. Therefore, the purpose of this study is to establish typical quantitative inversion and eversion motion of the hindfoot during tiptoe and Coleman block tests utilizing 3-D motion capture. A further purpose is to demonstrate feasibility of this clinical assessment paradigm for patient populations commonly evaluated in motion analysis centers via examples.

### 2. Materials and methods

Institutional review board approval was received to conduct this prospective descriptive study establishing typical quantitative movement data. Typical developing subjects were recruited via advertisements in the hospital to relatives of clients and staff and to school aged tour groups. Subjects between 5–21 years of age were recruited to match the age range referred to our Motion Analysis Center and were screened to be non-symptomatic, without musculoskeletal or

\* Corresponding author.

E-mail address: [mmcmulkin@shrinenet.org](mailto:mmcmulkin@shrinenet.org) (M.L. McMulkin).

<https://doi.org/10.1016/j.gaitpost.2019.04.021>

Received 8 November 2018; Received in revised form 7 February 2019; Accepted 22 April 2019

0966-6362/© 2019 Elsevier B.V. All rights reserved.

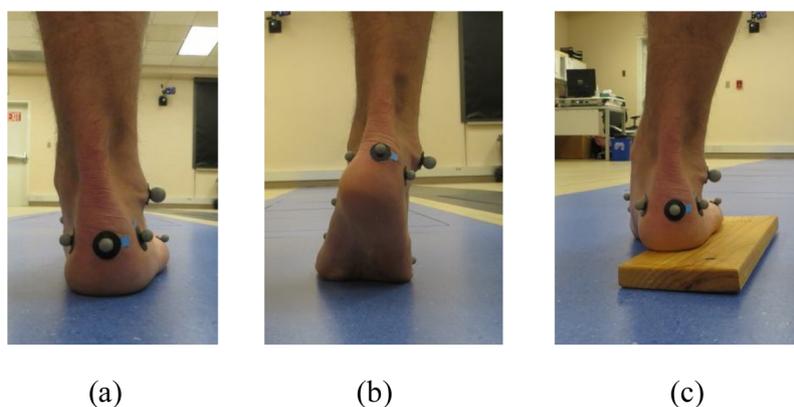


Fig. 1. Example testing positions for right foot: a) typical standing hindfoot position, b) tiptoe test (inversion), c) Coleman block test (eversion).

orthopedic issues, currently affecting their gait. The modified Shriners Hospitals for Children – Greenville (mSHCG) segmented foot model [4] was employed to assess foot kinematics during gait and for the Coleman block and tiptoe tests. The Plug-in-Gait marker set along with additional foot model markers were placed on the subjects. Data was collected using a 12 camera Vantage (V16) Vicon camera system. Only segmented foot kinematics for coronal plane eversion and inversion of the hindfoot relative to the tibia during Coleman block and tiptoe tests were considered for this portion of the study.

A single trial of the tiptoe test was collected to assess both feet during the same trial followed by two trials of the Coleman block test, one for the left foot and one for the right foot (Fig. 1). For the Coleman block test the subject’s hindfoot and fourth/fifth metatarsals were placed on a 2 cm block with the first to third metatarsals allowed to pronate to the floor. Typical standing hindfoot position, with the feet plantigrade, was collected from the start of the tiptoe trial (Fig. 1a). Maximum hindfoot inversion achieved was extracted from the tiptoe trial (Fig. 1b). Maximum hindfoot eversion achieved was extracted from each Coleman block trial (Fig. 1c). Data from both feet were used to determine descriptive data.

### 3. Results

Thirty-two subjects (12 males, 20 females), n = 64 feet; age range 5 to 21 years participated in this study. Descriptive statistics for hindfoot motion from segmented foot model showed a mean of 6 degrees eversion during the Coleman block test and 10 degrees inversion during the tiptoe test (Table 1). Mean standing foot position was close to neutral (0.7 degrees eversion), so the test results also closely represent flexibility from standing (7 degrees from standing for the Coleman block test and 9 degrees from standing for the tiptoe test).

**Table 1**  
Hind foot position (in degrees) relative to tibia during typical standing, Coleman block test and tiptoe test.

	Mean (90% CI)	SD	Min	Max
Typical standing	0.7 (-0.3 to 1.7)	3.9	-7.3	10.8
Coleman block test	-6.3 (-7.4 to -5.2)	4.5	-16.2	4.4
Tiptoe test	10.1 (9.0 to 11.2)	4.5	0.2	22.8
Motion from standing to Coleman block	-7.1 (-7.9 to -6.2)	3.5	-15.6	0.6
Motion from standing to tiptoe test	9.4 (8.3 to 10.5)	4.4	2.3	20.5

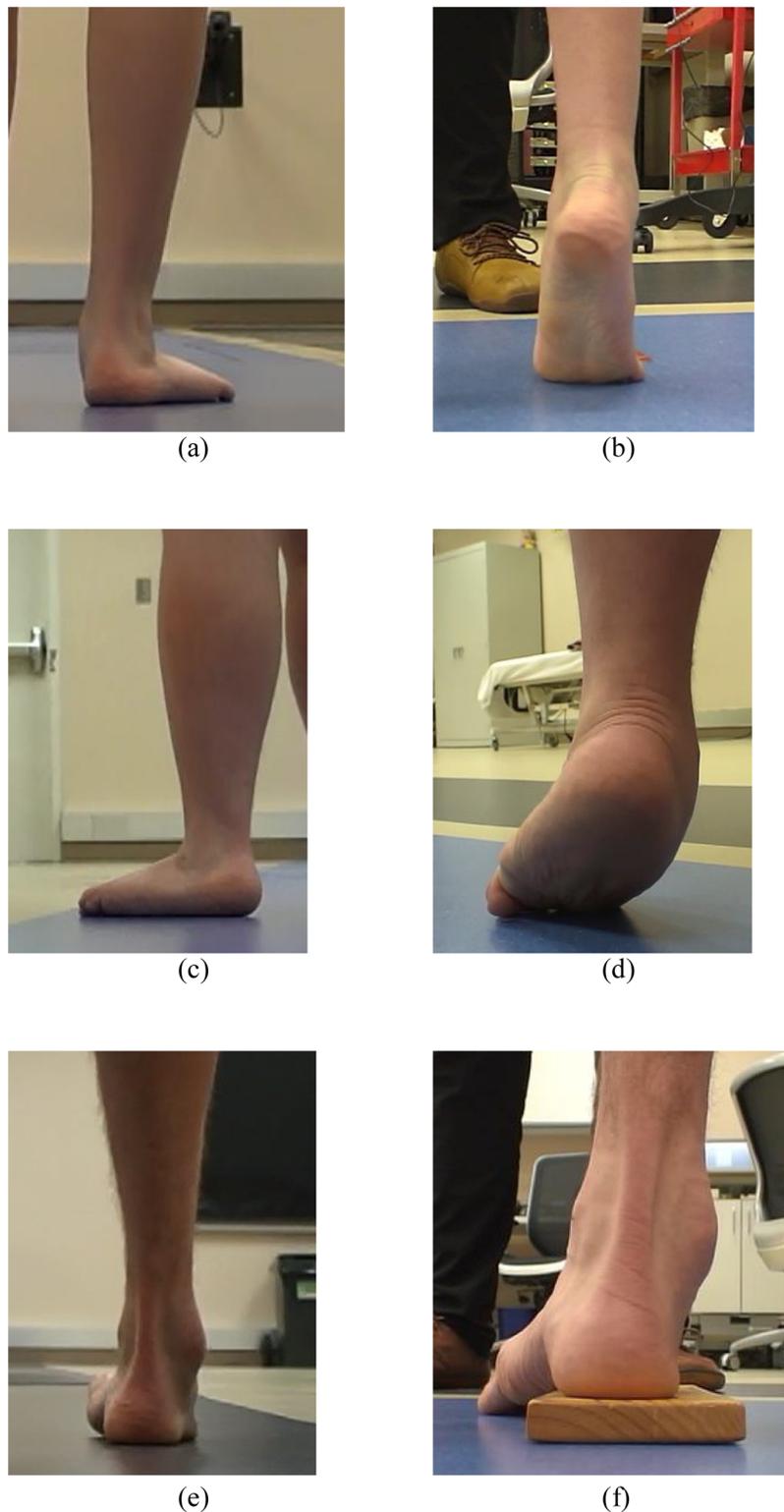
Positive values (+) are inversion; Negative values (-) are eversion. CI – Confidence Interval; SD – Standard Deviation.

Our Motion Analysis Center has been collecting segmented foot model quantitative assessment of the Coleman block and tiptoe tests as appropriate for clients presenting with foot concerns. To demonstrate feasibility for clinical applications, three cases are presented: an individual with pes planovalgus, tarsal coalition, and cavovarus foot deformity. Case 1 is an 11 year old male with bilateral out-toeing and painful planovalgus feet. He ambulated with hindfoot eversion throughout stance (Fig. 2a). He demonstrated hindfoot eversion during standing and 20° hindfoot inversion during tiptoe test (Fig. 2b). This showed that his planovalgus is flexible which led to a recommendation for custom orthotics. Case 2 is a 13 year old male with bilateral out-toeing and tarsal coalitions. He ambulated with hindfoot eversion throughout stance (Fig. 2c). He demonstrated hindfoot eversion during standing and only 1° of motion toward inversion (remaining in eversion) while performing the tiptoe test (Fig. 2d). This showed lack of hindfoot flexibility which led to a recommendation for tarsal coalition resection surgery. Case 3 is a 21 year old male with right hemiplegic cerebral palsy and a cavovarus foot. He ambulated with hindfoot inversion throughout stance and swing (Fig. 2e). Coleman block test showed correction to a neutral hindfoot (0°) position (Fig. 2f) from a standing position of 13° inversion. This showed flexibility of the hindfoot with ability to correct to neutral inversion/eversion which led to a recommendation for a custom medially posted orthotic versus surgical intervention which might include a tendon transfer as well as calcaneal slide osteotomy.

### 4. Discussion

The clinical assessments described as the Coleman block and tiptoe tests [1–3] are used to determine flexibility of the hindfoot in cavovarus or planovalgus feet. Quantitative results of this study indicate that typical feet will reach mean end values of 6 degrees eversion for the Coleman block test and 10 degrees inversion for the tiptoe test. Since mean standing position of the hindfoot was close to neutral (1° eversion) these values approximate the amount of hindfoot movement, from standing that occurs during these tests.

The hindfoot flexibility tests can be used to supplement typical walking kinematics that are unlikely to differentiate foot issues. For example, alterations in multi-segment kinematics of symptomatic individuals with tarsal coalitions are either minimal or similar to those with other foot disorders when walking in a laboratory. Walking in the laboratory setting is often not a strenuous enough activity to uncover kinematic deviations at the hindfoot, limitations in segmental excursions, or reproduce pain. Completion of the tiptoe test requires the patient to reach the end range of joint excursion where deviations, limited motion and pain can be appreciated. Specific values for the tiptoe or Coleman block tests to indicate pathology are not proposed by this study. Outcomes of these tests need to be corroborated with patient report and other clinical findings.



**Fig. 2.** Clinical application of quantitative testing of hindfoot mobility. Case 1 (out-toeing, planovalgus) a) Stance phase walking eversion, b) tiptoe test – quantified as  $> 20^\circ$  hindfoot inversion; Case 2 (out-toeing, tarsal coalition) c) Stance phase walking eversion, d) tiptoe test – quantified as  $< 1^\circ$  hindfoot motion; Case 3 (right hemiplegic cerebral palsy, cavovarus right foot) e) Stance phase walking inversion, f) Coleman block test – quantified as  $> 10^\circ$  motion from inversion to neutral.

Concerns with segmented foot models often include repeatability of kinematics and application to small feet. A limitation of the current study was a lack of conducting repeatability testing to assess intra or inter clinician variability, nor were multiple trials taken to assess within subject variability. However, for the mSHCG foot model [4], variability in static and dynamic hindfoot angles has been reported as less than  $3^\circ$

in typically developing children and patients with planovalgus feet for the specific motion of hindfoot version [5]. In terms of smaller foot concerns, the mSHCG foot model used 9 mm technical markers for dynamic tracking, with 5 mm hemispheres as anatomic markers in the static trial. The 5 mm markers should allow for accurate anatomic placement on small feet, although this was not quantified.

Application of the hindfoot flexibility tests can have limitations. The tiptoe test relies on adequate plantarflexion strength to raise up on to the toes which may not be present in clinical populations. The Coleman block test can create difficulty with balancing. One of the typically developing subjects in this study exhibited less hindfoot eversion during the Coleman Block test than in typical standing (Table 1). It is possible that the tip toe and Coleman block tests could be completed in a seated position if strength or balance is a concern. For the Coleman block test, placing only the lateral forefoot on a block has been shown as an alternative (although this requires sufficient dorsiflexion). Mobility of the hindfoot while seated for these tests is an area for future research.

In conclusion, clinical testing for foot disorders can incorporate quantitative assessment utilizing hindfoot flexibility tests. Descriptive values have been reported to assist in the assessment of hindfoot flexibility in clinical cases, within the context of typical values and movement.

#### Conflicts of interest

None.

#### Source of funding

None of the authors received financial support for this study.

#### References

- [1] S.S. Coleman, W.J. Chesnut, A simple test for hindfoot flexibility in the cavovarus foot, *Clin. Orthop.* (1977) 60–62.
- [2] J.P. Trost, *Clinical assessment*, in: J.R. Palsy Gage, M.H. Schwartz, T.F. Koop Novacheck (Eds.), *Identif. Treatemnt Gait Probl. Cereb.* 2nd ed., MacKeith Press, London, 2009, pp. 181–204.
- [3] A.I. Ricco, B.S. Richards, J.A. Herring, *Disorders of the foot*, in: J.A. Herring (Ed.), *Tachdjians Pediatr. Orthop.* 5th ed., Elsevier, Philadelphia, 2014, pp. 791–883.
- [4] P. Saraswat, B.A. MacWilliams, R.B. Davis, A multi-segment foot model based on anatomically registered technical coordinate systems: method repeatability in pediatric feet, *Gait Posture* 35 (2012) 547–555, <https://doi.org/10.1016/j.gaitpost.2011.11.022>.
- [5] P. Saraswat, B.A. MacWilliams, R.B. Davis, J.L. D'Astous, A multi-segment foot model based on anatomically registered technical coordinate systems: method repeatability and sensitivity in pediatric planovalgus feet, *Gait Posture* 37 (2013) 121–125, <https://doi.org/10.1016/j.gaitpost.2012.06.023>.